Moment Arm Plasticity in Response to Loading History during Growth

Matthew Q. Salzano.[1,2*], Suzanne M. Cox[1], Stephen J. Piazza[1], and Jonas Rubenson[1,2]
[1]Biomechanics Laboratory, Dept. of Kinesiology, The Pennsylvania State University, University Park, PA 16802
[2]Integrative & Biomedical Physiology, The Pennsylvania State University, University Park, PA 16802
Email: *salzano@psu.edu

Introduction

A muscle's moment arm influences locomotor function since it determines the joint moments produced by a given muscle force and the muscle's shortening velocity for a given rate of joint rotation. While moment arms have been found to vary with locomotor specialization [1], it is not clear how much of this variation is due to nature versus nurture. Here, we investigate whether muscle moment arms are modulated in response to loading history during the growth period in an animal model.

Methods

Guinea fowl (N = 23, *Numida meleagris*) were split evenly into three groups at 4 weeks of age: exercise (EXE), sedentary (SED), and botox (BTX). EXE birds were housed in large pen (3.14 m^2), with ample room for running and perches for jumping. SED and BTX birds were house in small pens (1 m^2) with low ceilings to restrict movement and jumping. BTX birds were also given bilateral injections of botulinum toxin-A (4 units (LD50)/kg) in both gastrocnemius muscles every 5 weeks to promote further disuse, while SED and EXE received sham saline injections. The protocol lasted until birds were 6 months-old, for a total of 4 injections for each group, at which point they were sacrificed.

A tendon travel protocol was used to measure plantarflexion moment arms of the Achilles tendon. Retroreflective markers were placed on dissected limbs to track their movement and calculate joint angles. The Achilles tendon was attached to a linear transducer to measure excursion. Third-order polynomials were fit to the excursion-angle data in order to calculate moment arm as the derivative of excusrsion with respect to angle. Moment arms were found across the range of motion corresponding to that seen during the stance phase of running (30°-90°) [2].

Linear mixed models were run to find the effect of group on moment arm and any interaction between group and angle. The model was run twice: once classifying angle as a continuous variable, to analyze the moment arm curves, and again with angle classified as a categorical variable (at 30°, 60°, and 90°) to permit mean comparisons at each of the three chosen angles.

Results and Discussion

While there were no large, clear differences in moment arm between groups, there were several indications of moment arm plasticity during the growth period. There were significant group ($p = 0.040$) and interaction ($p < 0.001$) effects when the model was run with angle as a continuous variable, in which the EXE group appears to have a slightly larger moment arm than the other two groups. When angle was treated as a categorical variable, however, no significant interaction or group effect was found ($p = 0.104$ and $p = 0.092$, respectively; Fig. 2). This seemed to indicate no difference between groups but might be explained a lack of statistical power due to a small sample size. Our findings are suggestive of moment arm plasticity and adaption in response to loading during growth, but the amibiguous results from statistical tests suggest that caution should be taken when interpreting these results.

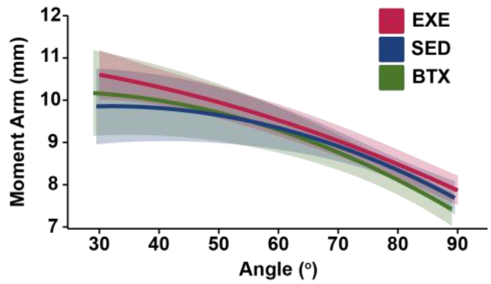

Figure 1: Moment arm plotted versus joint angle. Solid lines represent mean moment arm for each group. Shaded regions: ± 1 SD of the mean.

Significance

These data are among the first to indicate that muscle moment arms may be affected by loading history across growth. The functional consequences of increases in moment arm remain unresolved. On one hand, muscle moment generating capacity increases with increasing moment arm. This could permit high moments with smaller muscle mass, an advantage for reducing the energy required to grow and maintain muscle tissue. But muscle force capacity may also decrease due to a greater influence of force-velocity effects with a larger moment arm. Further work is required to quantify which of these factors dominates.

We encourage future studies exploring developmental plasticity of muscle moment arms. These studies will benefit from addressing deficiencies in statistical power and examining the mechanisms underlying links to locomotor function.

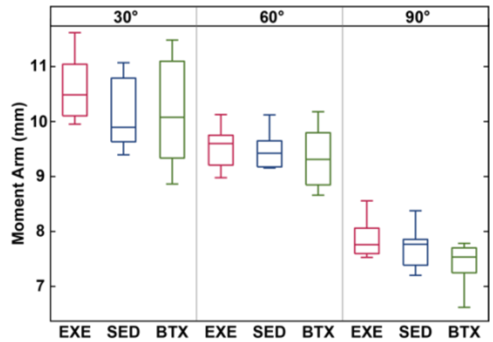

Figure 2: Boxplots of moment arms at 30°, 60°, and 90°. Box represents 25th-75th percentiles. Line within box represents median.

Acknowledgments

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References

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